Session 1:
Reliability of Electronics Under Extreme Environments

Electronics Design for the Low Temperature Microgravity Physics Facility in the Space Station Environment

http://ltmpf.jpl.nasa.gov/ — cleared 1999

INTERNATIONAL SPACE STATION

Jet Propulsion Laboratory
California Institute of Technology

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ATW in Electronics Parts and Packaging for Space and Aeronautic Applications

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Acknowledgement

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Jet Propulsion Laboratory
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Low Temperature Microgravity Physics Facility (LTMPF)

Team Members Contributed to this Presentation:

JPL:

- Dr. Talso Chui - Project Element Manager
- Arvid Croonquist - Project System Engineer
- Michael Taylor - Mission Assurance Manager
- Anthony Lai - Electronics and Software Cog. Engineer

Ball Aerospace and Technologies Corporation, Boulder:

- Dr. Jim Eraker - System Engineer
- Randy Abbott - Electronics Engineer

LTMPF Overview

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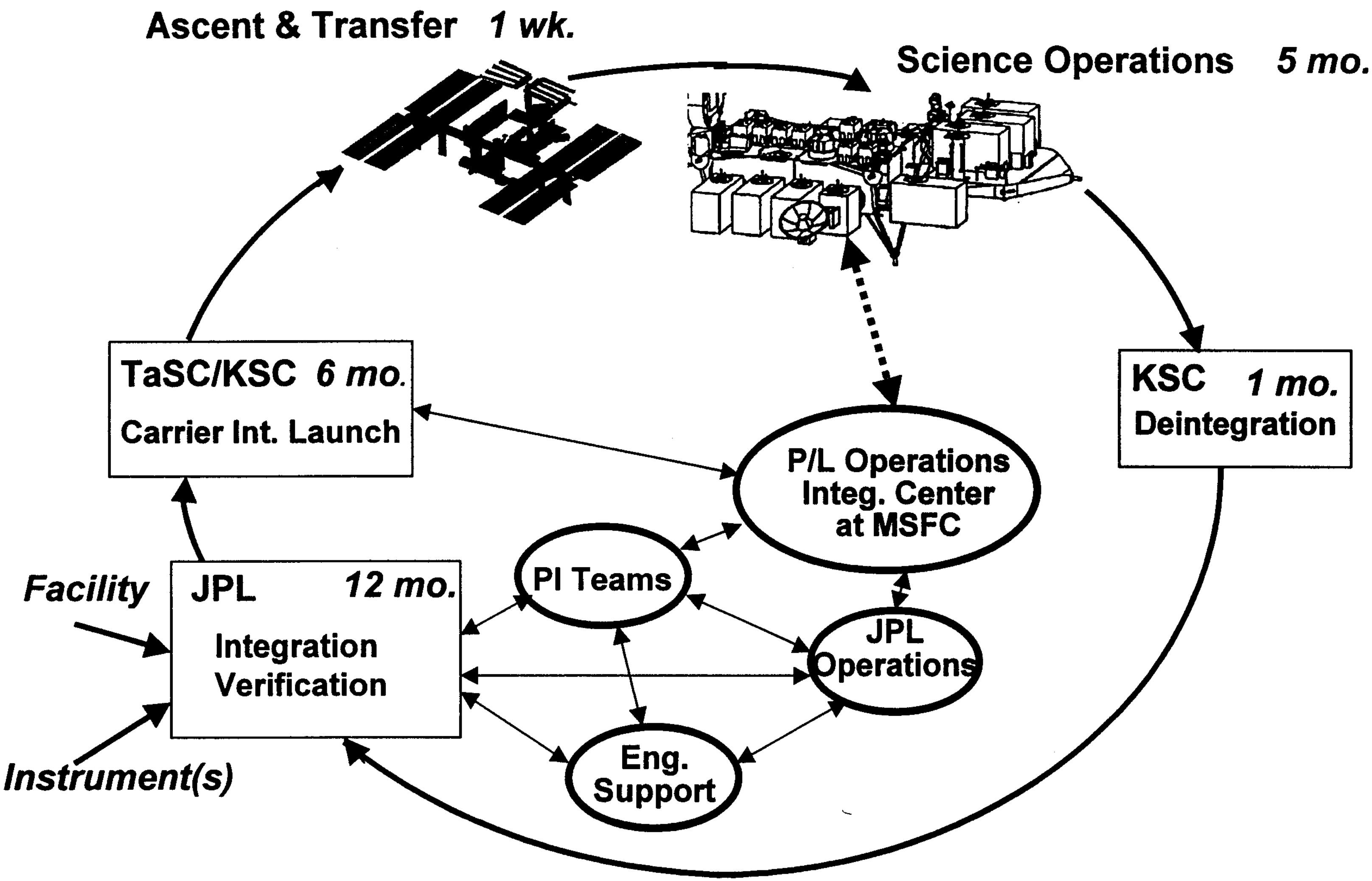
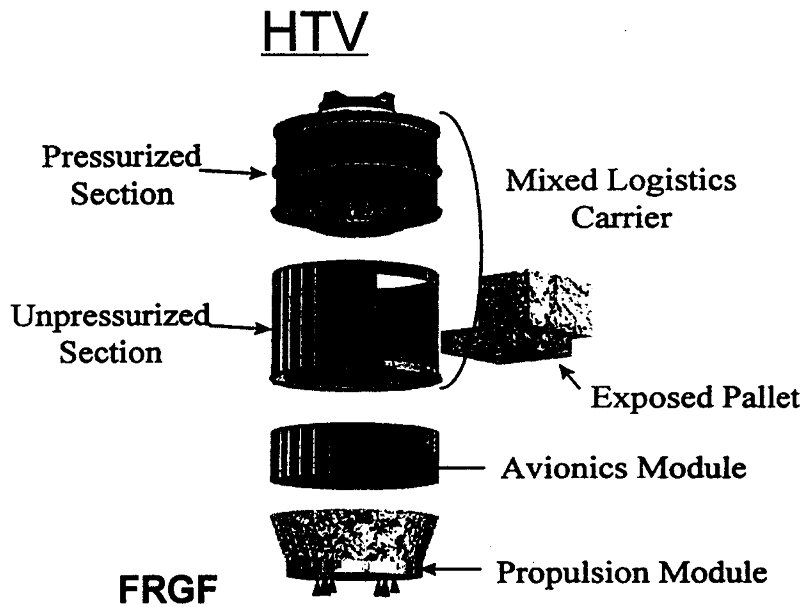
- Provide an unpressurized facility for fundamental physics experiments on the International Space Station (ISS).
- Each facility can be launched on either the Space Shuttle or the Japanese H-IIA Transfer Vehicle and attached to the Japanese Experiment Module's Exposed Facility on the ISS.
- JPL provides an infrastructure to support science investigators while Ball Aerospace and Technologies Corporation is the industrial partner in co-designing and building the facility.

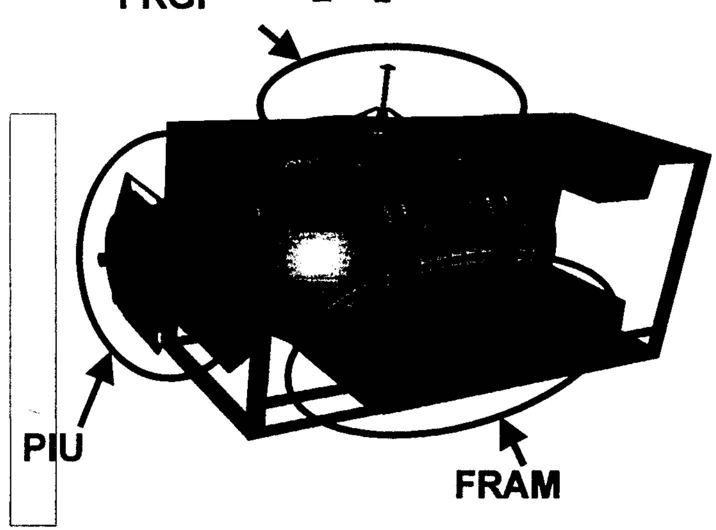
LTMPF Approach



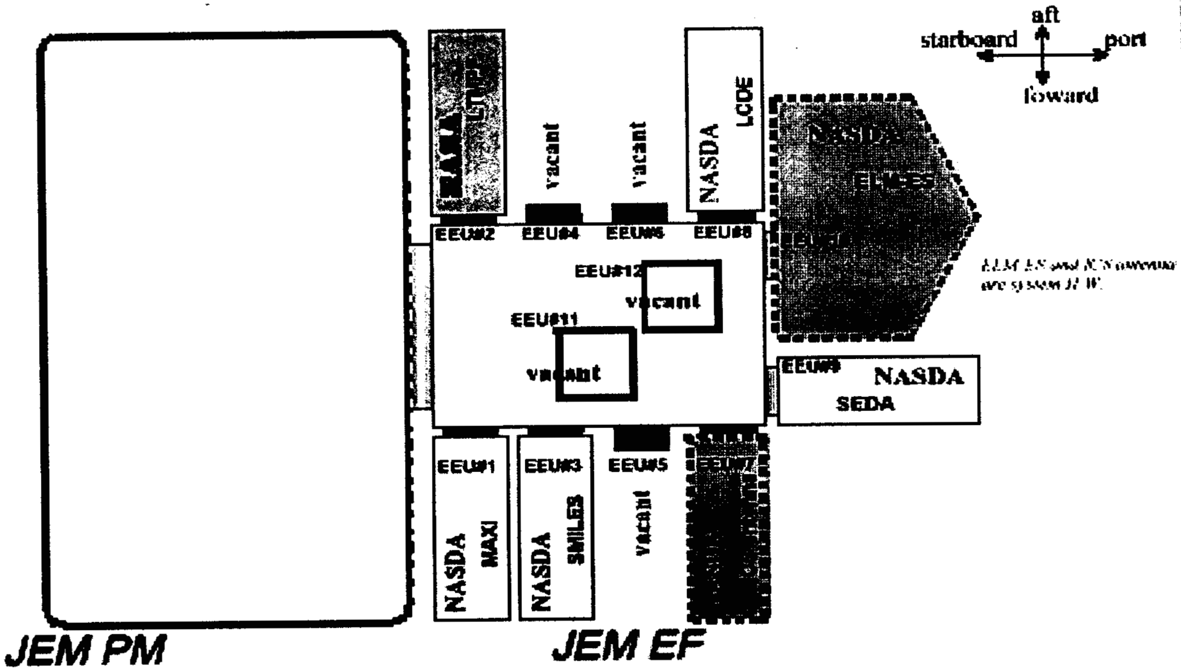
Launch Carriers and Interfaces

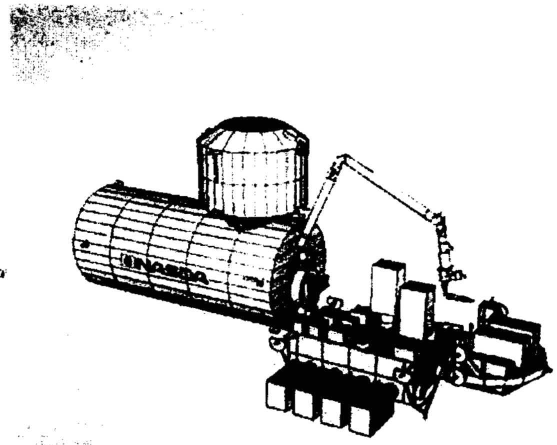
- **Several launch carriers can transport a JEM-EF Payload to ISS.**
  - –Unpressurized Logistics Carrier (ULC) by Boeing/Brazil
  - –HII-A Transfer Vehicle's Exposed Pallet (HTV-EP) by Japan
- **The ULC can return JEM-EF payloads in the STS.**
- **The Flight Releasable Attachment Mechanism (FRAM) has been identified as the common carrier interface.**
- **The Flight Releasable Grapple Fixture (FRGF) and FRAM will be used to transfer the LTMPF between the ISS/JEM-EF and a carrier.**
- **The NASDA Payload Interface Unit (PIU) attaches LTMPF to JEM-EF.**





LTMPF Accommodation





Early Drawing of Japanese Experiment Module (JEM) & its Exposed Facility (JEM-EF)

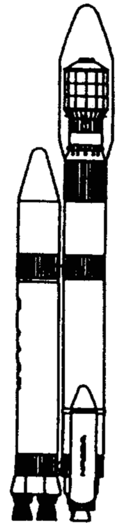
JEM-EF attached payload meets the requirements of LTMPF:

- Envelope - Mass: ≤ 500 kg, Volume: 0.8m x 1.0m x 1.85m
- Power - Experiment: < 1kW @ 120 Vdc; Survival: ~ 100 W
- Commanding/Timing: via MIL STD 1553B bus
- Telemetry: via Ethernet bus
- Thermal Interface: Fluid Cooling Loop (if required)
- Custom Interface: Payload Interface Unit

LTMPF Environment

The facility must survive most extreme envelope:

- Launch (H-IIA and STS) & return (STS)
  - Acoustics: 141.7 dB
  - Random Vibration: 3.9 G_{rms}
  - Pyroshock: 500g at LTMPF's carrier interface
- Unpowered transfer between the carrier and ISS
  - Keep critical components within their non-operating temperature range (-40 °C to +75 °C).
- On-orbit waiting for return
  - Keep critical components within their non-operating range with one temperature sensor and < 100W of keep-alive power.
- Radiation Susceptibility
  - Total Ionizing Dose = 2.5 Krads (4 years on JEM/EF i.e. 2 missions; assume RDM=2 & 100mil Al equivalent shielding).
  - No non-recoverable SEE for LET < 37 LET (MeV-cm2/mg).



H-IIA Rocket

LTMPF System Overview

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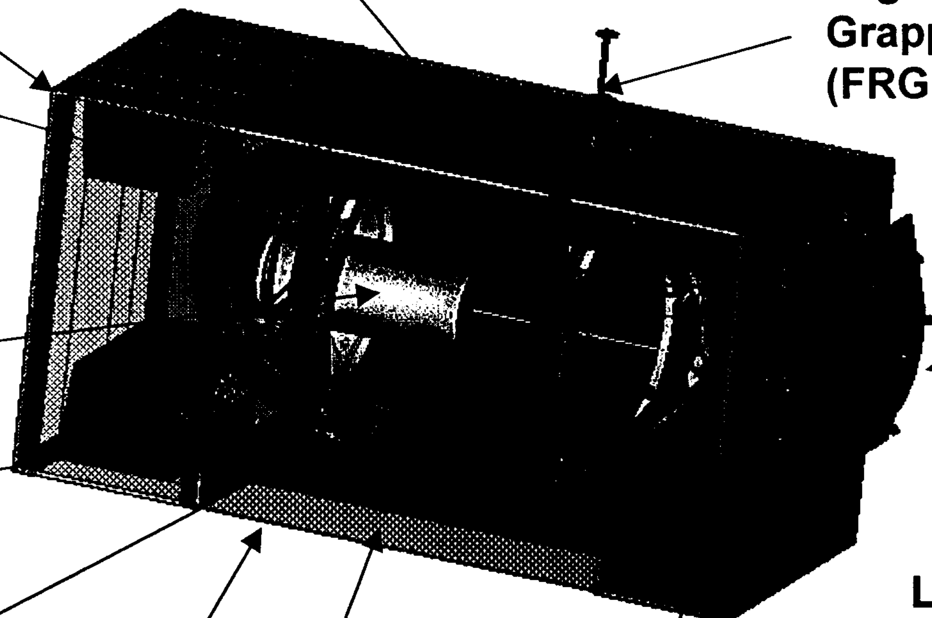
LTMPF
- JEM-EF Standard Payload
- 500 kg; 1.0 x 1.85 x 0.8 m^3



LTMPF Design Concept

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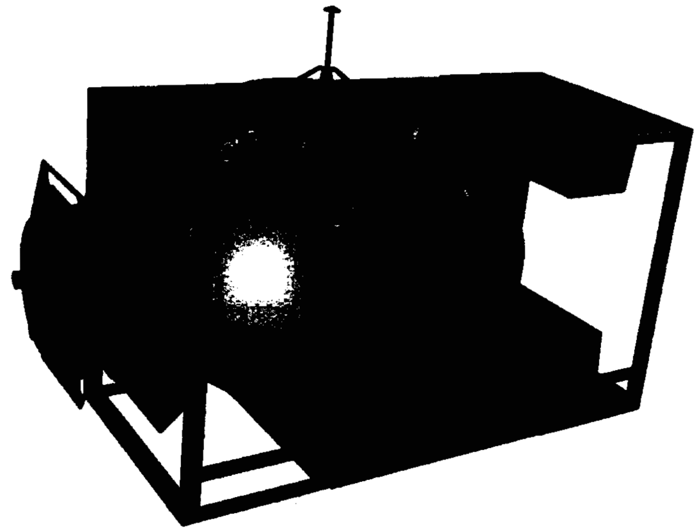
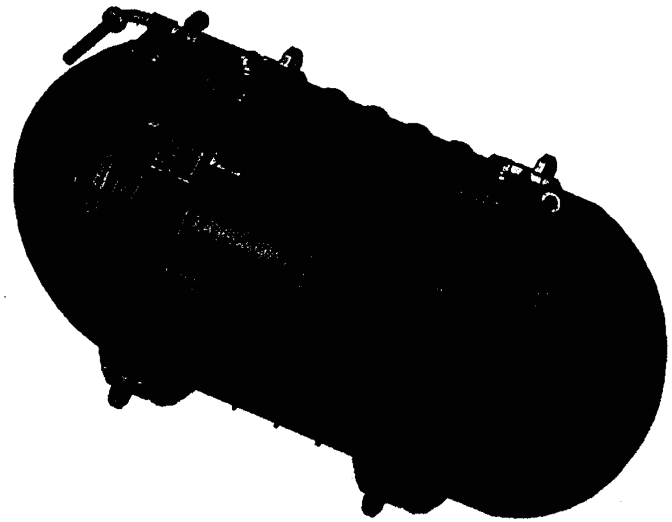
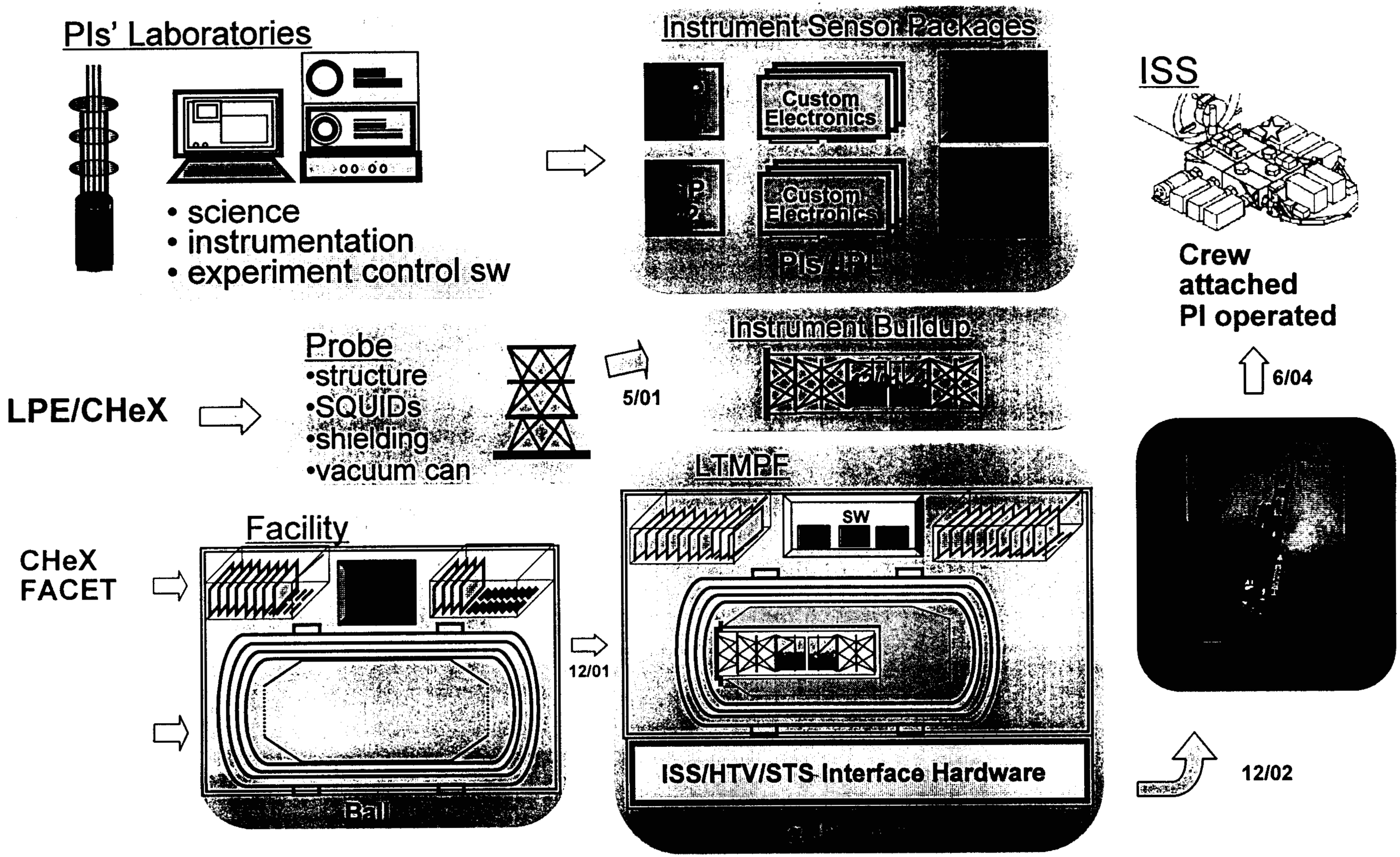
LTMPF = "facility" + "instrument"

- **The facility is the re-usable infrastructure:**
  - Provide a dewar, facility electronics, facility software and structure
  - Physical and software interfaces in which an instrument is integrated.
  - Provide a controlled environment by its instrumentation and sensors.
  - Design is driven by SRED.
  - Built by Ball Aerospace.
  - Maintained by JPL.
- **The instrument is experiment-specific:**
  - Probe provides mechanical and thermal support for science experiments.
  - Electronics for PI-specific sensors can be integrated with the VMEbus interface.



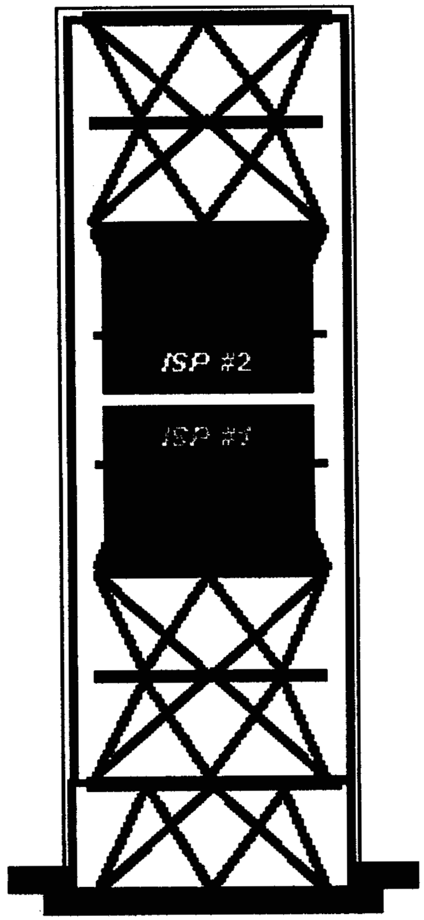


LTMPF Development Roadmap



LTMPF Instrument Overview

- Large experiments volume
- Allowable experiment mass: $\geq$ 5 Kg
- Dewar temperature: 1.4- 2.0K
- Thermal and magnetic shielding
- Up to 10 DC SQUIDs: lower noise, higher bandwidth and stability
- Up to 14 Germanium Resistor Thermometers (GRT);
- Numerous (precision) heaters, electrical feedthroughs, plumbing feedthroughs and etc.
- Allow optical feedthroughs, secondary coolers and etc.
- Extensive inheritance



LTMPF Electronics Overview

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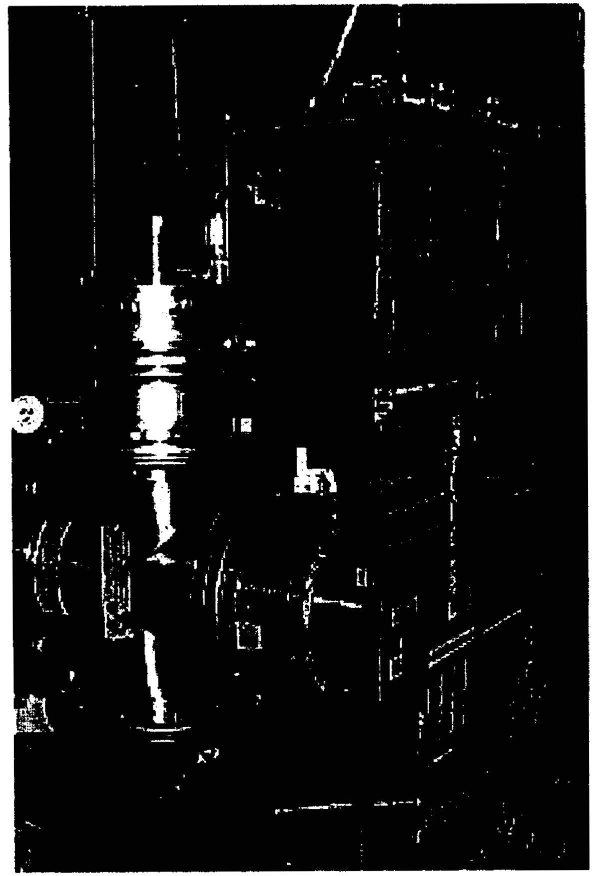
- **LTMPF Flight Electronics has four major electrical interfaces:**
  1. Dual redundant 1553B bus
  2. IEEE 802.3 ethernet bus
  3. VMEbus for payload internal functions
  4. Power conversion from the raw 120VDC input power bus
- A PowerPC 750 flight computer is the baseline for providing the interface processing and payload functions.
- A 1553B interface board is required to interface with the space station uplink capabilities.
- Several custom instrument boards will support functions for low-resolution thermometry, high-resolution thermometry, housekeeping sensors interfaces, cryogenic valve controllers and interfaces to charge particle monitors and accelerometers.



LTMPF Radiation Environment

Testing Logistics

- Two manufacturers (Aitech Defense System Inc. and DY 4 Systems Inc.) were investigated.
- Based on similar needs and budget constraints, the LTMPF project at JPL coordinated the testing efforts with the FCF project at GRC to perform radiation testing on computer boards with similar capabilities from the two identified manufacturers.
- The LTMPF project requested the JPL radiation group to lead the testing for a Aitech S245 single board computer and a C127 communication controller.
- Similarly, the FCF project requested the GSFC radiation group to lead testing for a DY4 179 single board computer.
- Both radiation groups worked jointly during all testing activities, shared raw test data and published the final test reports.

LTMPF Radiation Environment

Approaches for Aitech Computer Boards (COTS)

Proton Tests

- A proton test was completed at the Indiana University Cyclotron Facility on a in November of 1999.
- No catastrophic latchup was observed during the exposure to a 196 MeV proton beam.
- A radiation report is publicly available for the test results.

Heavy Ion Tests

- A heavy ion test is scheduled for early June of 2000 at Brookhaven National Laboratory in New York.
- Several components are delided and they will be exposed with ions of proper energy levels (6.3 MeV, 11.4 MeV, 26 MeV, 37 MeV and 60 MeV - based on the project requirements).

After Radiation Tests

- Based on test results, parts replacements, lot traceability, upscreening and latchup protection circuits may be required to mitigate the identified risks.

LTMPF Temperature Environment

The temperature environment is complicated by the operational scenarios of the facility:

Survival from launch to attachment at the space station

- During ascending of the space transfer vehicle, an internal battery will be used to perform critical valve operations. These operations are critical to the facility in maximizing a proper cryogenic environment for science operations.
- The electronics will be kept with a minimal survival power of less than 100W from launch to transfer and attach onto the space station.

Nominal on-orbit operations

- With the assistance of a thermal cooling mechanism, the facility electronics box temperatures shall be maintained within the range of -15°C to +50°C.

Payload shutdown with minimal survival power

- After the experiments are completed, the facility will be shut down and the 100-Watt survival power will be provided to the facility until a space shuttle is available to return this facility to KSC for ground servicing.
- The expected environmental temperature ranges from -40°C to +75°C.

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Other Related Environment

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Vibration

- The vibration environment involves all 3-axis of accelerations as shown in the following table:

Random Vibration Zone/Assembly	Frequency, Hz	Flight Acceptance (FA) Level	Design, Qual, Protoflight (PF)Level
Electronic Boxes and Components less than 23 kg (50 lb)	20	0.0125	0.025
	20 - 50	+6 dB/octave	+6 dB/octave
	50 - 600	0.075 g^2/Hz	0.15 g^2/Hz
	600 – 2000	-4.5 dB/octave	-4.5 dB/octave
	2000	0.0125	0.025
	Overall	9.1 G_{rms}	12.9 G_{rms}

- The LTMPF facility implements standard spacecraft practice in the electronics box design and electronics packaging methods.

Shock

- The dominant shock factor is from the pyro separation with the HTV rocket:
    - +8 dB per octave from 100 Hz to 800 Hz
    - 500g from 800 Hz to 5000 Hz

LTMPF Electronics Architecture

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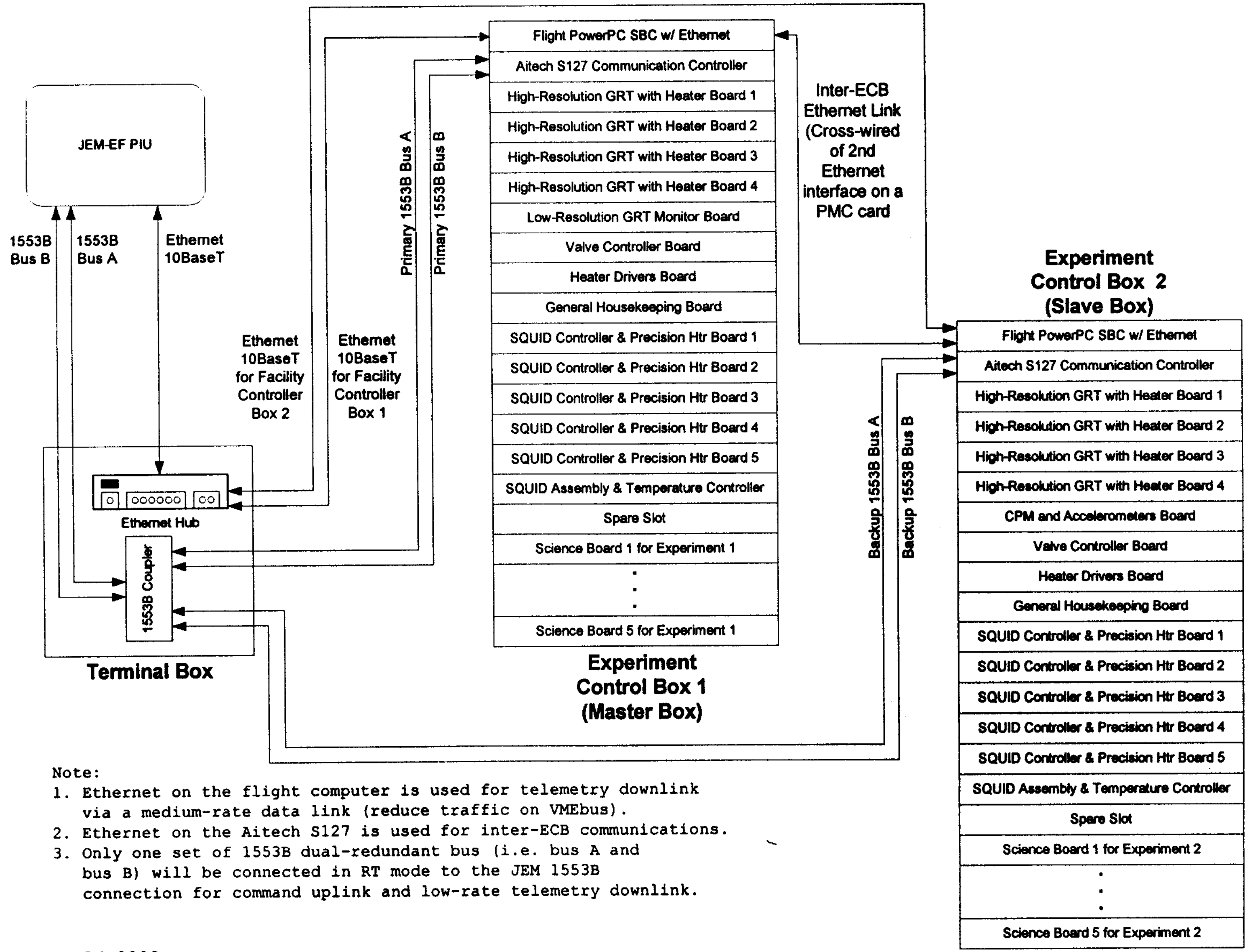


Note:
1. Ethernet on the flight computer is used for telemetry downlink via a medium-rate data link (reduce traffic on VMEbus).
2. Ethernet on the Aitech S127 is used for inter-ECB communications.
3. Only one set of 1553B dual-redundant bus (i.e. bus A and bus B) will be connected in RT mode to the JEM 1553B connection for command uplink and low-rate telemetry downlink.

Redundancy and Operations

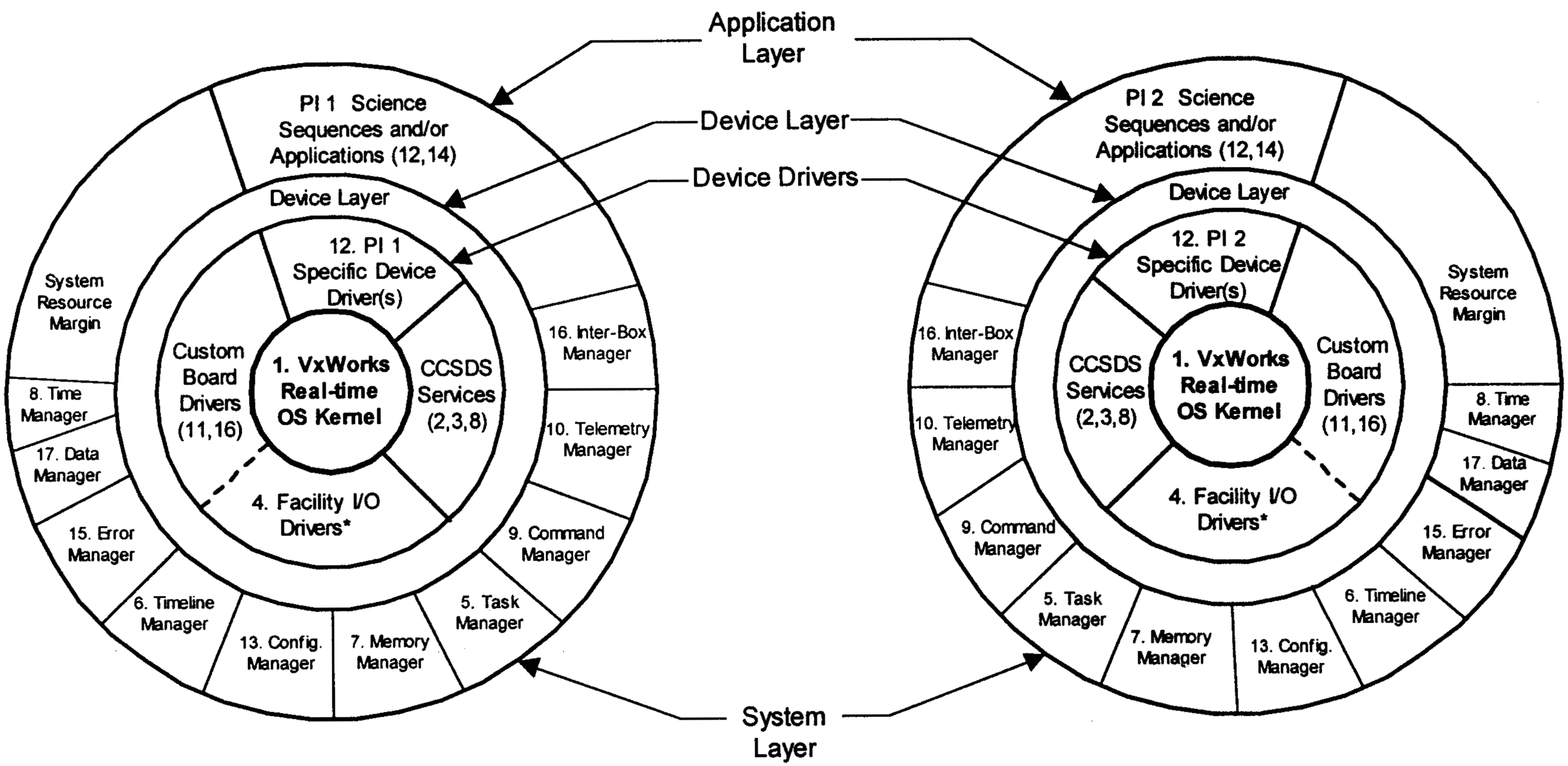
Data Interface Redundancy

- 1553B couplers/splitters provides 2 sets of dual-1553B uplink connections.
- A ethernet hub allows both ECBs to downlink telemetry.
- Secondary ethernet interface provides inter-ECB communications.

Operations

- Two ECB exercise master and slave operations.
- The facility can be reset at board level and ECB level.
- Charge particle monitors provide measurements of the radiation environment to provide real-time decision to shutdown electronics from unpredicted events such as solar flares.
- 3-axis accelerometers monitor accelerations of the facility.
- In addition to ECC on volatile memory, the volatile memory (DRAM) and non-volatile memory (SRAM) are checked periodically to ensure the integrity of these memory devices.
- Cache memory may not be used for flight due to its vulnerability to single effect upset.

LTMPF Software Architecture



***Note:**
1. Private device drivers are system-critical and/or time-critical (hard real-time) such as 1553B bus I/O.
2. Public device drivers are PI-oriented but time-criticality may still be applied.

Reduce Risks in Software Design

- **In order to reduce risks that are identified from the current electronics design, LTMPF flight software is designed to provide additional redundancy and autonomy:**
  - Exercise board-level and box-level recovery.
  - Execute onboard periodic and event-based error handler manager.
  - Provide telemetry buffer/throttling and routing capabilities.
  - Verify memory integrity periodically.
  - Use limit checkers on facility critical items.
  - Monitor critical health parameters of the facility.
  - Implement master and slave operations.
  - Develop software algorithms to shutdown facility based on environmental inputs from the charge particle monitor and the accelerometers.

Conclusion

- The exposed facility environment on the International Space Station is an extreme environment in terms radiation and temperature survivability.
- Accommodations of various launch vehicles introduce additional constraints from pyro shocks.
- Use of COTS needs to be handled carefully in terms of manufacturing process control and parts traceability.
- Use of COTS requires a close relationship with the manufacturer so that changes in parts and design can be communicated effectively.
- The environmental specifications of our COTS electronics are verified through environmental testing and analyses.
- Risks introduced by the environment can be mitigated in providing redundancy and implementing an integrated software and electronics design.